DOCUMENT RESUME

ED 420 715 TM 028 437

AUTHOR Liew, Chong-Wah; Treagust, David F.
TITLE The Effectiveness of Predict-Observe-Explain Tasks in Diagnosing Students' Understanding of Science and in Identifying Their Levels of Achievement.
PUB DATE 1998-04-00
NOTE 22p.; Paper presented at the Annual Meeting of the American Educational Research Association (San Diego, CA, April 13-17, 1998).
PUB TYPE Reports - Research (143) -- Speeches/Meeting Papers (150)
EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS *Academic Achievement; Action Research; Comprehension; Constructivism (Learning); Evaluation Methods; Foreign Countries; *High School Students; High Schools; *Performance Based Assessment; *Science Education; Sciences; *Student Evaluation
IDENTIFIERS Grounded Theory

ABSTRACT

This study involves action research to explore the effectiveness of the Predict-Observe-Explain (POE) technique in diagnosing students' understanding of science and identifying their levels of achievement. A multidimensional interpretive framework is used to interpret students' understanding of science. The research methodology incorporated constructivist action-inquiry principles, grounded theory development, and triangulation of multiple data sources, multiple data collection methods, and multiple theoretical perspectives. Data from a class of 18 11th-grade students include students' written POE task response, interviews with individual students, and in-class discussions. The POE tasks were concerned with the expansion of water, solubility of salt, and power and resistance of light globes. Variations in student responses suggest that uniform observation outcomes may not always be assumed even for the well-designed POE intended to provide an obvious and clear observation outcome. Data also suggest that POE tasks are effective in capturing a range of possible student observation and prediction outcomes when they are worded in an open-ended format. Results imply that POE tasks can be used to design learning activities insightfully to start with the students' viewpoints rather than the teacher's or scientist's. Findings also suggest that POEs are effective in facilitating the teacher and the students in documenting student achievement and profiling student progress. (Contains 6 tables, 4 figures, and 33 references.) (SLD)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

ED 420 715

The Effectiveness of Predict-Observe-Explain Tasks in Diagnosing Students' Understanding of Science and in Identifying their levels of Achievement.

Chong-Wah Liew and David F Treagust
Science and Mathematics Education Centre
Curtin University of Technology
GPO Box U 1987
Perth, Australia 6845

ABSTRACT

This study involves action research by the first author to explore the effectiveness of the Predict-Observe-Explain (POE) technique in diagnosing students' understanding of science and in identifying their levels of achievement. A multidimensional interpretive framework is employed to interpret students' understanding of science. Of prime interest in this paper are students' understanding of science concepts from an ontological and epistemological perspectives. The research methodology incorporates constructivist action-inquiry principles, grounded theory development and triangulation of multiple data sources, multiple data collection methods and multiple theoretical perspectives. Data sources include students' written POE tasks responses, interviews with individual students, and in-class discussions with students.

The POE tasks are concerned with expansion of water, solubility of salt, and power and resistance of light globes. The data demonstrate how students' prior knowledge can affect their prediction, observation and interpretation of phenomena. Variations in students' observations suggest that uniform observation outcome may not be always assumed even for a well designed POE intended to provide an obvious and clear observation outcome. Furthermore, the data also suggest that POE tasks are effective in capturing a range of possible students observation and prediction outcomes when worded in an open ended format.

Diagnosis of students' understanding of science revealed common ideas amongst students that are contrary to scientists' science across grade levels. The results imply that POE tasks can be used by teachers to insightfully design learning activities that start with students' viewpoint rather than the teacher's or scientist's. The findings also suggest that POEs are effective in facilitating the teacher and his students to document and to identify students' levels of achievement across levels, strands and substrands of the Australian student outcome statements and the profiling of students' progress over time.

Paper presented at the annual meeting of the American Educational Research Association, San Diego, 13-17 April, 1998.

TM028437

U.S. DEPARTMENT OF EDUCATION
Office of Educational Research and Improvement
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)
☑ This document has been reproduced as received from the person or organization originating it.
☐ Minor changes have been made to improve reproduction quality.
• Points of view or opinions stated in this document do not necessarily represent official OERI position or policy.

PERMISSION TO REPRODUCE AND DISSEMINATE THIS MATERIAL HAS BEEN GRANTED BY
Chong-Wah Liew
TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)

Introduction

The objectives of this research are to explore the effectiveness of the Predict-Observe-Explain teaching/learning technique in: diagnosing students' understanding of science, and identifying students' level of achievement with reference to the science student Outcome Statements for Australian schools. This paper describes five POEs, each with a different purpose in relation to identifying specific learning outcomes. The first and second POEs focus on students' conceptual responses, ideas and beliefs. The third POE diagnoses students' responses across age levels, while the fourth POE diagnoses one Grade 10 student's epistemological and ontological understanding. The fifth POE profiles student's progress over time.

The results of this work could be used by teachers to insightfully design learning activities and strategies that start with students viewpoint rather than the teacher's or scientist's. This study takes some essential issues into consideration when using the POE teaching/learning technique to obtain credible information on students' understandings. The results may impress upon teachers to appreciate the need to obtain credible information when using any method of probing into students' understanding. Moreover, credible information obtained on students' understanding would help teachers to identify students' level of achievement and plan further learning activities to assist students' progress in science. In short, the results of this study have implications for curriculum development and learning strategies, teacher development, and the promotion and assessment of students' understanding and level of achievement from a constructivist viewpoint.

Over the last two decades a vast body of evidence in the literature has echoed the need for science educators to understand students' understanding of science concepts, processes and phenomena as a prerequisite to improving teaching and learning in science. This need has been influenced by Ausubel's theory of learning which takes into account what the learner already knows and the constructivist's view of learning which acknowledges the personal and social construction of knowledge (Driver, Squires, Rushworth & Wood-Robinson,1994; Treagust, Duit & Fraser, 1996).

To unravel students' understanding of science, a wide range of techniques have been developed and documented by researchers (Carr, 1991; Duit, Goldberg & Niedderer, 1992; White & Gunstone, 1992). 'The interview about instance/events' (Osborne & Freyberg, 1985), for example, has been widely used with individual students. Another technique developed by White and Gunstone (1992) which has been widely used with student groups is the Predict-Observe-Explain (POE) learning/teaching sequence. In the POE learning/teaching sequence, students are informed about an experiment or demonstration which will be performed and, based on their current understanding, students are asked to predict what will happen and provide reasons for their predictions. The experiment or demonstration is then performed and the observations made by the students are probed. When the predictions and observations are inconsistent with each other, the students' explanations are explored. Occasional use of POEs in primary schools and high schools has been described respectively by Aguis (1993), Costa (1994), Tytler (1993), and Grant, Johnson and Sanders (1991), Liew and Treagust (1995), and White and Gunstone (1992). Although POEs have been used in schools, their effectiveness in diagnosing students' understanding of science concepts, processes and explanation of natural phenomenon is still an open question.

In line with constructivist epistemology which recognises the nature of science knowledge as personal and social construction to make sense of observations and natural phenomena, Treagust (1996) developed a multidimensional interpretive framework to look into students' understanding involving conceptual change. He argued that a multidimensional interpretive framework would provide a more adequate, holistic, complete and informative explanation and interpretation of students' understanding. His framework comprises three aspects, namely, epistemology, ontology, and social/affect of students' understanding. The framework also takes into account the dynamic process of change over time from pre-instructional conceptions to that of scientists' and the learning pathway between them (Scott, 1991). Similarly, this study adopts a multidimensional interpretive framework to analyse students' understanding of science.

A collaborative national education initiative provides a framework for curriculum development in science education, setting broad goals and defining the scope and sequence of learning science in Australian schools. Teachers are encouraged to generate learning tasks and activities which produce students' work. Interpretation of students' work, such as portfolios and journals, are used as indicators to identify their level of achievement for each outcome statement in each strand and substrand of science content, concepts and processes in each level of the science profile.

Methodology

This research project adopts an interpretive action research approach to generate understanding of students' understanding and level of achievement in science. The interpretive research aspect of this approach is based on the qualitative methods of participant observational research on teaching reviewed by Erickson (1986). The distinctive characteristic of interpretive research is its concern with generating understanding about the significance of what is happening in a particular social setting, such as the classroom, from the perspectives of the participants, namely, the teacher-researcher and the students. To generate a plausible and credible account of students' understanding of science, the methodological strategies drawn from the field of interpretive research (Denzin, 1998; Duit, Treagust & Mansfield, 1996; Erickson, 1986) include :

- minimising underdetermination of the teacher-researcher by employing triangulation in the form of multiple data sources, multiple methods of generating data, and multiple theoretical perspectives;
- avoiding the predominance of researcher's preconceptions by generating emergent students' conceptions (i.e. grounded theory) and searching for disconforming evidence before making assertions on student conceptions;
- establishing a rapport with students so that interviews would be informed good conversations; and
- avoiding unethical actions by maintaining researcher's concern for safe guarding students' learning opportunities and guarantees of confidentiality and anonymity.

Data sources in this research project include the students' written POE responses, in-class discussions with students, interviews with individual students, portfolios and journals of students. Data collection methods employed are based on the Predict-Observe-Explain learning/teaching sequence (White & Gunstone, 1992) and interview about events (Carr, 1996; Osborne & Freyberg, 1985).

Initial Phase of this Action Research: Observing Students' Responses

To evaluate the effectiveness of a POE in providing insights into 18 grade 11 (age 16-17 years) students' understanding on heat and expansion of water, we designed a POE involving the expansion of coloured water in a glass tubing fitted to a round bottom flask filled with coloured water as shown in figure 1.

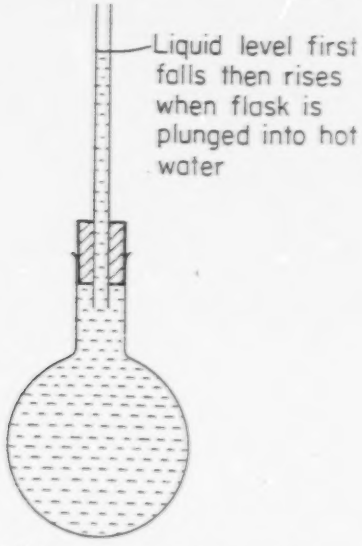

Figure 1 . Expansion of a liquid

Heat and expansion of water was chosen because it is prevalent in both primary and secondary school. Heat is experienced by students at a very early age, and it is likely that experience with situations involving heat and expansion form the basis of prior knowledge or beliefs. The experiment was conducted in groups of two students. When the flask is plunged into hot water, the level of the coloured water in the glass tubing first falls slightly and then starts to rise steadily. The initial fall in the level of the water is caused by the expansion of glass which becomes heated and expands before the heat has time to be conducted through the glass into the coloured water. The water level later rises as the liquid becomes heated and expands.

The instructional strategy

At the onset, students were told that they would perform an experiment and they were asked to predict what will happen and provide reasons for their predictions. The experiment was performed and students wrote down their predictions and observations.

Predict

The lesson began with the first author showing the class some glass tubing fitted to a round bottomed flask filled with coloured water. Students were told that this was not a test, and their views were requested on their explanation of this phenomenon. Subsequently, students were independently asked to write down their answers to the following question:

Predict what will happen to the water level in the glass tubing if the round bottomed flask is plunged into the hot water from the initial moment and onwards? State and explain the reason(s) for your prediction.

Observe and Explain

The next stage of the lesson sequence involved the students performing the experiment in nine groups of two. They were reminded that the Bunsen flame had to be removed as soon as the water in the beaker was boiled. The round bottomed flask then was plunged into the beaker of hot water. The students were requested to independently write down their observations by answering the following question:

What happened to the water level in the glass tubing when the flask is immersed into the hot water from the initial moment and onwards? State and explain the reason(s) for your observations.

In the course of the experiment, students made independent observations while sharing the apparatus in groups of two and no discussions were allowed. In the next stage, students were asked to make comparision between their own prediction and their observations by answering the following question:

Compare your observation with your prediction. Are they in agreement or disagreement? Explain with your reason(s).

Finally, students within each group discussed their answers to the three questions after which they each wrote down their final reasons and explanations.

Results and discussion

Table 1. Prediction and observations about the change in water level (n=18).

	Number of student observation	
	Rise	Initial drop
Predict Rise	13	3
No change	1	1
Initial drop	0	0

Students' observations compared to their predictions about the level of water in the glass tubing are presented in table 1. Of the 18 students, none predicted an initial drop, two predicted the water level would be unchanged, and 16 predicted an immediate rise. Of the 16 students who predicted a rise, 13 stated that they did observe an immediate rise. As it can be difficult to miss the initial fall of the liquid in the glass tube, these findings may be due to students' poor observational skills. However, these grade 11 physics students were among the most able science students of their year. Consequently, from our perspectives, the data suggest that these students' prior knowledge and beliefs, and hence their expectation of the outcome, influence their observations. For example, as evidence of her strongly held beliefs influencing her observations, one student who predicted an immediate rise in the water level expressed that she already knew the outcome because of her former experiences with similar experiments, and her own reading in books.

Table 2. Students' reasons and explanations for predicted rise in the water level in the glass tubing (n=16)

Reason	Explanation: Microscopic	Explanation: Macroscopic
Water expands when heated (9)	Molecules move quicker (4) Molecules move faster and take up more space (1) No explanation (4)	
Water pressure increases(4)	Molecules more energetic and collide more frequently(1) Molecules move faster and further apart (1) No explanation (1)	Water pressure causes expansion (1)
No reason (3)	Particle move vigorously (1) Molecules move faster and further apart (1)	Water becoming cold (1)

Although students were not asked to explain their observations in any specific manner, many made use of their background knowledge and provided explanations in terms of molecules and their energy. Of these molecular explanations, only one of the 18 students gave a complete scientific explanation that water expands because molecules move faster and take up more space (see Table 2). The majority of the 18 students seemed to hold incomplete, incorrect, or inconsistent links between the macroscopic concepts of liquid expansion and the microscopic concept of the kinetic theory of matter. Although one could account for students' responses to this POE in terms of poor observational skills, we argue that the data did demonstrate how students' prior knowledge and beliefs can affect their observations and interpretations of new learning. However, variations in students' observations suggest that POEs need to be designed to produce 'on-the-spot', obvious and clear observation outcomes. Subsequently, two more POEs were designed and trialled.

Phase Two of this Action Research: Observing Students' Ideas and Beliefs

To collect data on a group of grade-11 students' ideas and beliefs on solubility we used the Predict-Observe-Explain (POE) learning sequence, explained in detail in White and Gunstone (1992), and in Liew and Treagust (1995). Specifically, we designed the POE task for salt and water as follows:

1.Prediction/Explanation before the experiment

Predict what will happen to a teaspoon of table salt if it is dropped into a cup of water. State and explain the reason(s) for your prediction.

2.Observation/Explanation during the experiment.

Describe what happens to a teaspoon of table salt if it is dropped into a cup of water. State and explain the reason(s) for your observation.

3.Comparison of prediction and observation after the experiment.

Compare your observation with your prediction. Are they in agreement or disagreement ? Explain with your reason(s) .

4.Group discussion on their answers to the above three questions and writing down their final reasons and explanations.

.A second Predict-Observe-Explain learning sequence was also performed using a different solvent (cooking oil) for salt. The salt/water and salt/cooking oil situations are chosen because they are relevant to the daily out-of-school experiences. Students would have similar experiences at home in their parents' kitchen.

Results and Discussion for Salt-in-Water POE

All the nine grade-11 students predicted and observed the 'disappearance' of salt in water. Their explanations are as follows: salt is dissociated (1)
salts atoms/molecules are dissociated into sodium ions and chloride ions (2)
salt ions are dissociated by water molecules (2)
salt ions combine with water molecules (2)
salt become ions surrounded by water molecules (2)

Students' view of the solubility phenomenon is based on their sensory experience of salt having the property of becoming invisible in water which tend to focus on the solute (salt). However, two students were able to provide an explanation (salt ions are dissociated by water molecules) that is related to scientists' view of solubility.

Results and Discussion for Salt-in-Oil POE

Students' reasons for their predictions and observations were listed and grouped into categories based on their similarities of wording and their use of distinctive words or concepts. Results of the predictions and observations of the class of nine grade-11 students are given in Table 3.

Table 3 Predictions and observations of grade-11 students (n=9)

		Predicted		
		soluble	insoluble	don't know
Observed	soluble			
	insoluble	4	3	1
	slightly soluble	1		

The four students who predicted the solubility but observed the insolubility of salt in cooking oil provide the following prediction reasons:
1. salt ionises and mixed with oil to form a solution (1)
2. salt dissolves in oil (2)
3. Salt molecules join onto the hydrocarbon chain of oil (1)

Their observation reasons are as follows:
1. Oil does not dissolve salt (3)
2. Oil is not a solvent (1)

The four students could have derived their reasons from the previous salt-in-water POE experience. Their predictions and reasons were influenced by their prior experience and learning. When their prediction is contradicted by their observation of the insolubility of salt in oil, active reconstruction of explanations occurs. For these four students, their contradictory experience draws their attention to the problem and created an opportunity for reconstructing their view. Their reconstructed view suggests a way they perceived the nature of the solubility phenomenon. Ontologically speaking (Treagust, 1996, P.6), they view solubility as a property of the substance or solvent. That is, 'oil does not dissolve salt' or 'oil is not a solvent'.

The student who predicted the solubility and observed the slight solubility of salt in oil provide his prediction reason as 'oil contains water'. His observation reason is 'oil has a small amount of water so a small portion of salt was dissolved'. The student's prediction and observation is influenced by his prior knowledge, reason and, expectation learned during the salt-in-water POE and from other previous occasions. Although the salt-in-oil POE was designed to provide an on-the-spot, obvious and clear observation outcome (8 out of 9 students observed the insolubility of salt in oil), he tended to observe or focus on the aspect of the experiment that supported his prior or pre-conceived reason and expectation. He tended to see what he wanted to see during the experiment. This variation in student observations suggests that uniform observation outcome of a well designed POE cannot be always assumed by the designer. However, the data does suggest that a well designed POE intended to produce 'on-the-spot', obvious and clear observation outcome does reduces variation in students' observation. Furthermore, the data also suggest the effectiveness of POE in an open-ended format (without giving a choice of possible responses) in capturing a range of possible students' observation and prediction outcomes.

The student who was unable to make a prediction but observed the insolubility gave his observational reason as 'oil and water did not mix physically or chemically'. This student's ontological understanding is associated with the miscibility property of different substances.

The three students who predicted and observed the insolubility of salt in oil provide the following prediction reasons:
1. salt remain as crystal (1)
2. ionic substance (salt) only dissolve in water to form ions (1)
3. oil is not a good solvent (1)

Their observation reasons are:
1. organic substances (oil) do not dissociate ionic substances into their component ion(1)
2. no bond breaking by oil/ salt remain as solid (1)
3. oil cannot dissociate the ions of salt (1)

In terms of the ontological categories, students view the solubility phenomenon as a property of substances. Examples of students' POE responses that can be placed in the property ontological category are: 'oil is not a good solvent', 'oil don't dissolve salt', and ionic substances dissolve only in water'. Students also view the solubility phenomenon as a process of interaction between salt and oil using the particle model. Examples of students' POE responses that may be placed in the process ontological category are: 'oil cannot dissociate the ions of salt' and 'no bond breaking by oil'.

Scientists' conception of solubility

In order for solution to occur, the electrostatic attractive forces between the particles (molecules, atoms, ions) of the solute must be overcome by the larger attractive forces between solute and solvent particles (Nusirjan & Fensham,1987). The underlying meaning the students have for the words (dissociate and bond breaking) they used to explain the dissolving process is not elaborated. Hence, the extend to which students' views are congruent to those of scientists' is unclear. However, the data suggest that students do have an incomplete particle model view of the dissolving process indicated by their use of words like 'ions of salt', and 'component ions' to describe the form of the solute.

The Third Phase of this Action Research: Diagnosing students' understanding across grade levels

In the next phase of this action research, a POE on light globes was conducted to diagnose students' understanding across grade levels. This POE sequence was conducted to a class in each grade level (grade 9, 11, 12). Using a double class period of 80 minutes, each class is shown two electric light globes (36W 12V and 18W 12V) functioning normally when each is connected to a 12 volt DC power supply. The globes were then connected in series to the 12 volt DC supply. Before the circuit was switched on, students were independently asked to write down their answers to the following question:

Predict which globe will glow brighter if the circuit is completed. State and explain your reason(s) for your prediction.

In the next stage of this POE demonstration sequence, the teacher completes the electric circuit. The students were requested to independently write down their observations by answering the following question:

When the circuit is completed, which globe glows brighter? Describe your observation with regard to the relative brightness of each globe. State and explain your reason(s) for your observation.

In the course of this stage of the demonstration, student groups of six each were asked to come to the teacher's bench, in turn, to have a closer view of the experiment. Students were asked to make independent observations and no discussions were allowed.

In the next stage, students were asked to make comparisons between their own predictions and their observations by answering the following questions:

Compare your observation with your prediction. Are they in agreement? Explain with your reason(s).

Finally, students in groups of three discussed their answers to the three questions after which they each write down their final reasons and explanations. At each stage of the POE sequence students were reminded that is it not a test and their views were requested.

Results and Discussion

Students' reasons for their predictions and observations were listed and grouped into categories based on their similarities of wording and their use of distinctive words or concepts. Results of the predictions and observations of the class of twenty five grade 9 students are given in Table 4.

Table 4 Predictions and observations of grade 9 students (n=25)

Predicted	36W	18W	same	total
Observed (18W)	21	3	1	25

The 21 students who predicted that the 36W globe would glow brighter but observed a brighter glow of the 18W globe give 'more power or watt' as their reason for their prediction. Their reasons for their observed brighter glow of the 18 W globe are :

1) power is taken from the 36W globe (7),
2) 18W globe accepts power quicker (7),
3) more electricity runs through the 18W globe (4),
4) 18W globe needs less electricity to glow (1),
5) low watt of the 18W globe could handle lower voltage (1) and,
6) no reasons (1).

Three students give the same reasons for their prediction and observation of the brighter glow of the 18W glove. Their reasons are :

1) 18W globe has to compete with the 36W (1)
2) 18W globe is closer to the power source/ first to receive power (1)
3) all energy went into the 18W globe (1)

The student who predicted that both globes would glow with equal brightness but observed the brighter glow of the 18W globe gives 'equal power sharing, each receiving lesser power than before' as the reason for his prediction. His reason for the observed brighter glow of the 18W globe is that the '18W globe does not need much power to light up'. The results of the predictions and observations of the class of six grade-11 students are given in Table 5.

Table 5 Predictions and observations of grade-11 students (n= 6)

predicted	36 W	18 W	same
observed (18 W)	3	2	1

There are three students who predicted that the 36W globe would glow brighter but observed the brighter glow of the 18W globe. Their reasons for their predictions are :
1) 36W globe draws more current (1)
2) more watt (2)

Reasons for their observations are :
1) 18W globe is closer to power source (1)
2) 18W globe only lets 18W of electrical energy to the 36W globe (1)
3) electrons went passed the 36 W globe into the 18W globe where the positive charges are(1).

Two students give the same reasons for their prediction and observation of the brighter glow of the 18W globe. Their reasons are :
1) closer to power source (1)
2) 18W globe took most of the energy (1)

The student who predicted equal brightness of the globes but observed a brighter glow of the 18W globe gives 'both globes receive 12V each' as his prediction reason and '18W globe took most of the energy' as his observation reason. The results of the predictions and observations of the grade-12 class of ten students are given in Table 6

Table 6 Predictions and observations of grade-12 students (n = 10)

predicted	36W	18W	same
observed (18W)	6	3	1

There are six students who predicted that 36W globe would glow brighter but observed the brighter glow of the 18W globe. Their predictions reasons are :

1) more watts (3)
2) 36W globe receives negative current first (2)
3) 36W globe has smaller resistance (1)

Their observation reasons are :

1) 18W receives current first (1)
2) 36W globe requires more current to light up / equal current is received by both globes (2)
3) 18W globe used most of the current (2)
4) no reason (1)

There are three students who predicted and observed the brighter glow of the 18W globes. Their prediction reasons are :

1) 18W globe has greater resistance (1)
2) greater resistance/operating at a higher watt (1)
3) first globe to receive electricity (1)

Their observation reasons are :

1) greater resistance/globe took most of the electricity (1)
2) operating at a higher watt (1)
3) first globe /took away most of the current (1)

The student who predicted equal brightness of the globes but observed a brighter glow of the 18W globe give 'same current and voltage' as his prediction reason and 'same current but higher potential difference across the 18W globe' as his observation reason.

The Scientist's Conception

The specifications of the globes (18W 12V ; 36W 12V) imply a higher resistance of the 18W globe ($R= V^2/P$). In the series circuit, more heat per second, consequently the brighter glow, is generated in the 18W globe for the same amount of current that passes through its filament ($P=I^2R$). During the demonstration, the phenomenon is clearly observed, with the 18W globe glowing at near normal brightness while the 36W globe takes several seconds to reach only a dull red colour.

The higher resistance of the 18W globe is due to the greater number of vibrating metal atoms in its filament that obstruct the drift of the free electrons through the circuit. Collisions occur between the free electrons and the metal atoms. At each collision, the electrons lose some of their translational kinetic energy to the vibrating metal atoms in the form of greater additional vibrational kinetic energy. The greater additional vibrational energy is experienced by the observer as heat or brighter glow in the filament of the 18W globe (Hewitt, 1992; DeJong et al. 1990; Nelkon & Parker, 1978).

Data analysis and interpretation of students' responses reveal that students' science and theories about the relative brightness of the globes are personal constructions that are largely incongruent to those of the scientist. We would like to call them alternative conceptions. There are commonalities in the ideas constructed among the students.

Some common students' alternative conceptions are :

1.Globes with higher specification power will glow brighter. Students most likely could have derived this idea from their experiences with globes used in their homes.
2.The globe that is closer to the power source glows brighter because it is the first to receive the current or power.
3.The current is not the same throughout the series circuit. More current is believed to be flowing through the brighter globe.
4.The lower power specifications globe needs to compete with the globe with a higher power specification by glowing brighter. This suggests that electric globes can have anthropomorphic property.

Ideas number 1,2,3 are consistent across year levels. This suggests the persistence of students' science or alternative conceptions inconsistent to those of scientists from lower school (year 9) into upper school (year 11 and 12).
Some students' conceptions that are related to the scientist's are:

1) It is the globe's operating power and not its specification power that determines the brightness.
2) The globe that has the greater share of electricity from the power source glows brighter.

The data suggest the effectiveness of POE in diagnosing students' understanding across grade levels.

The Fourth Phase of this Action Research: Diagnosing a Grade 10 Student's Epistemological and Ontological Understanding

The following two POEs were designed to evaluate the effectiveness of POEs in diagnosing a grade 10 student's epistemological and ontological understanding, and in identifying her level of achievement according to the Australian student outcome statements. These POEs were administered to a class of 20 mixed grade (9 to 12) students in a local metropolitan high school.

The first POE responses of Becky, a grade 10 student is described as follows:

Two electric light globes (18W 6V and 3W 6V) function normally when each is connected to a 6-volt DC power supply. The globes are then connected in series to a 6-volt DC power supply.

1. Predict which globe will glow brighter if the circuit is completed. State and explain the reason(s) for your prediction.

> I think that the larger globe will glow brighter. The reason for this is because the direct current starts at the globe that is where there is more current than the smaller globe which is where the current is returning back to the battery. There is also more watts so that could also cause a difference.

2. When the circuit is completed, which globe glows brighter? Describe your observation with regard to the relative brightness of each globe. State and explain the reason(s) for your observation.

> When the circuit is complete, the smaller globe glowed brighter than the larger globe. The larger globe did not even glow. I am not 100% positive why but I think it had something to do with the placement of the globes but I think more the number of watts because there were 3 watts in the smaller globe the current when it passed through the larger globe increased the brightness of the globe.

3.Compare your observation with your prediction. Are there in agreement or disagreement ? Explain with your reason(s).

> No, they were not in agreement. What I thought would happen didn't.

4. Discuss your answers to the above three questions in your group and write down your final reasons and explanation.

> We all come up with the solution that the smaller globe should have been placed at the beginning of the current flow and the larger globe at the end of the flow. We think this will cause a difference in the result and cause both globes to light up.

This student uses her idea of the bigger watt globe consumes more current and being the first to receive the current to account for its brighter glow during the prediction part of the POE. This part of her POE response indicates a sequential current consumed ontological model which is further evident by the following interview transcript excerpt:

Teacher: Why is the current through the larger globe more than the smaller globe ?
Becky: Because of the greater watt and I thought that the larger globe would light up more ..., the current will flow through like this way (towards 18W globe) so light up this one (18W globe) then like whatever is left over will light up ...(unclear) and keeps on going round.

When her observation (only the 3W globe lights up) contradicts her prediction, she did not change her view and explain that "it had something to do with the placement of the globes." She is still holding on to her sequential current consumed model which is further evident by the following interview transcript excerpt:

Teacher: ... in your observation in question 2, you notice that the smaller globe glowed but not the larger one. Although you are not 100% positive, but you think that it has something to do with the placement of the globes. Can you elaborate more on that ?
Becky: Well, cause the smaller globe fills up first, like lit up brighter, I thought that may be if the smaller globe is placed first and then the larger globe that the larger globe would have then lit up brighter, may be.
Teacher: Why do think so ?
Becky: Because like the smaller one even though 3W still lit up brighter than the 18W globe so I thought well, if the smaller globe first that is 3W, thought, because in my prediction I thought that it (the larger globe) would lit up brighter because it is so much greater in watt that the current will have been used up to light up that one. So thought well if the 3W first and then the 18W, may be the 18W would light up as well.

Her view is that the smaller globe being small in watt (3W) needs less current to light up than the larger watt globe (18W). By allowing a sequential current to flow through it first, there would be more left over current for the bigger watt globe to consume. The left over current may be sufficient to light up the bigger watt globe. Her epistemological commitment of her theory does not seem strong as indicated by her statements, like "I think" and "I am not 100% positive."

To further ascertain this student's ontological and epistemological view of the electric current, a POE using two globes of equal power specification (18W 6V) are used. Two electric light globes (18W 6V) function normally when each is connected to a 6-volt DC power supply. The globes are then connected in series to a 6-volt DC power supply. .

1.Predict which globe will receive current first and which one will receive more current if the circuit is completed. State and explain the reason(s) for your prediction.

> I think that the 18W globe no.1 will receive the current first because it is at the beginning. It is the first globe in the circuit but the second globe will glow the same amount or brighter cause the last globe in the circuit.

2. When the circuit is complete, which globe is the first to receive current and which one receives more current? Describe your observation. State and explain the reason(s) for your observation.

> The globes both light up at the same time but the first one probably light up first because it is at the beginning/first in the circuit. I am not 100% sure because it was too quick for the human eye. And they both receive the same amount of current which is 1.7 amps. The reason for this is I think because they are of equal watts and volts therefore they will be the same amps.

3. Compare your observation with your prediction. Are they in agreement or disagreement? Explain with your reason(s).

> The(y) are in agreement and disagreement. What I thought would happen could have happened but was too quick for the eye to see and I also said that the second globe would glow the same amount but then it went into disagreement which when I said "or brighter cause the last globe in the circuit."

4. Discuss your answers to the above three questions in your group and write down your final reasons and explanations.

> Our group had the same idea of which the first globe light up first but was undetectable by the human eye and they were of equal amps.

This student demonstrated that the idea of electric current is something that flows sequentially. Using the descriptors of Hewson and Hennessey (1992, p177), this student's conception is intelligible because she was able to describe it in her own words to make prediction and interpretation for her observation of the phenomenon. She knows what the concept means from her viewpoint. This is indicated by her prediction statement response " ...globe no.1 will receive the current first because it is at the beginning ..." and by her observation response statement. " ... the first one probably light up first because it is at the beginning/first in the circuit.". To this student, the idea of the superspeed sequential current is plausible because it fits in with her picture of the world, namely, the positions of globes in the series circuit. Statements like"...It is the first globe in the circuit ..." and "... it is at the beginning/first in the circuit ," are further reinforced during the reconciliation part (question 3) of the POE. Her reinforcement statement, "The(y) are in agreement ...what I thought would happen could have happened but was too quick for the eye to see." indicates that she believes this is how the world actually is.

This students superspeed sequential current theory is fruitful to her because she is able to use it to explain her apparent contradiction between her prediction and observation of the phenomenon. Her superspeed sequential current theory influenced her observation. Although she accepts her observation (both globes light up at the same time). She does it with reservation indicated by her epistemological comment "I am not 100% sure". She reinterpreted (Chinn and Brewer, 1993) her observation by arguing that the sequential

current flow "was too quick for the human eye". Furthermore, her epistemological commitment of her theory was further echoed during her group discussion which led her to make this comment: " Our group had the same idea of which the first globe light up first but was undetectable by the human eye". This superspeed sequential current theory is also indicated by her in-class journal statement, "I also learnt that positioning matters and that the first globe will light up first even though it is undetectable by the human eye." The data suggests that this student does not see cognitive conflict, at least entirely in the same way as the teacher/researcher, whose intention is to promote the scientist's conception of an instantaneous current to account for the simultaneous lighting of globes in a completed circuit.

Ontologically speaking, this student views current as something that has quantity and it flows. This is indicated by her matter-based predicates, equivalent words or phrases articulated (Chi et al, 1994) in her POE responses on the subject of current. These predicates are "globe no.1 will receive the current first", and "both globes receive the same amount of current which is 1.7 amps." And this matter called current has not only the properties of quantity and flow, but also it has the attribute of flowing at a super speed as indicated by the predicates like "too quick for the human eye" and "was undetectable by the human eye." Her further ontological electric current consumed model (used in her earlier POE) enables her to explain her observation of both the ammeters giving the same reading (1.7A). That is "both receives the same amount of current ...because they are of equal watts and volts..." The data indicate that neither the simultaneous lighting of the globes nor the same reading on the ammeters convince this student that the scientist's instantaneous current and current conserved model is the more appropriate explanation of the phenomenon observed.

However, the data suggest that POE's are effective in diagnosing the student's ability to apply her own ontological and epistemological understanding to explain specific events and phenomenon, namely the relative brightness of the globes, their simultaneous lighting up and same reading on each ammeter. Furthermore, the data also suggest that POE are effective in identifying the student's ability to reinterpret her observation and data that are contradictory to her prediction of the phenomenon. This student is able to argue conclusions during the POE activities on the basis of collected information (reading of ammeters), personal experience (simultaneous lighting of globes) and her own theory (superspeed sequential current consumed model). Her level of achievement identified here corresponds to level three of the working scientifically strand and the processing data substrand of the Australian student outcome statements. Although her arguments for her conclusions of "first globe recieves current first" and "both receive the same amount of current" are incongruous to that of the scientist's, she does propose possible arguments that fit her own ontological and epistemological understanding of the phenomenon. Written responses on her POE experiment worksheet reveal her ability to communicate her observation and make suggestions (using her own ontological view) about what her observations mean. This suggests that she also has achieved at level one of the working scientifically strand and the processing data substrand of the student outcome statements. The data suggest that POEs allow this student to demonstrate achievement across levels within a substrand and enable the teacher/researcher to observe and document a spread of achievement over a range of levels rather than a single outcome.

The Fifth Phase of this Action Research: Profiling Student's Progress Over Time

To evaluate the effectiveness of POEs in enabling the teacher-researcher to profile students' progress over time two POEs were designed and administered to the same mixed grade class in the fourth phase of this research. Specifically, the two POEs were administered to

the class to diagnose students' understanding of current flow in a parallel circuit. Responses of a grade-9 student, Sheila, to the first POE is described as follows:

An electric light globe (18W6V) functioning normally is connected to a dry cell (1.5V) and a switch as shown in figure 2

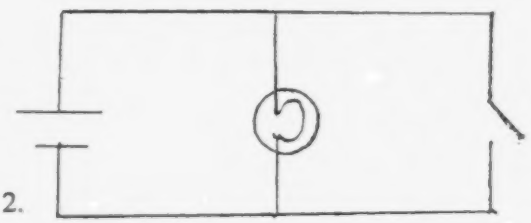

Figure 2.

1. Predict what will happen to the globe if the switch is turned on. State and explain the reason(s) for your prediction.

> I think that the globe will light up. This is because pressure is applied to the circuit but cannot get through until the switch is turned on to complete the circuit. In this case this is what happened.

2. When the switch is turned what happened to the globe? State and explain the reason(s) for your observation.

> When the switch is turned on the light globe turned off! This is because without the switch on the globe was already on, because it was a full circuit. However, when the switch was turned on electricity took the easiest way and went the circuit without the globe.

3. Compare your observation with your prediction. Are they in agreement or disagreement? Explain with your reason(s).

> My observation is in disagreement to my prediction. This is because I did not recognise that it was already a complete circuit and that the switch would turn it off.

4. Discuss your answers to the above three questions in your group and write your final reasons and explanations.

> The electricity took the easiest route when the switch was turned on which was to go straight and not light up a globe.

It should be noted that the circuit was not set up until students were asked to answer question 2. Sheila did not recognise the pre-existing circuit of the globe until the circuit was actually set up. The reason for her observation (the globe stop glowing) was that "electricity took the easiest way and went the circuit without the globe." When interviewed, her answer to the question " Was there electricity going through the globe when the switch was turned on?" was no. She was also asked to draw a diagram of the circuit showing the path of current as shown in figure 3.

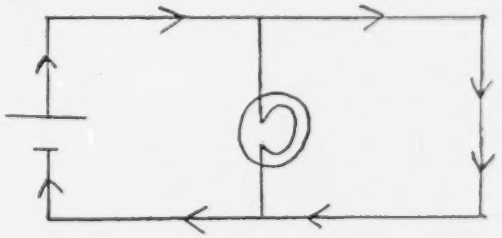

Figure 3.

Sheila's view of current as something that flows through the easiest route is a matter-based ontological category. Moreover, she did not realise that the easiest route is a path of least resistance and the globe being a metal conductor, although having a much higher resistance than the switch, would still have some current flowing through it, until during the class discussion.. This is indicated by the following excerpt of her in-class journal:

> ...because current always took the easiest route. However I did not know why current did this. Today's class discussion revealed to me that current took the easiest route because current flows through path of least resistance and the globe is resistance. This immediately got me thinking that the globe wires had no current but one of the class members pointed out that all metal conducts therefore the wire had to have current.

Her in-class journal also suggests that Sheila was able to evaluate her conclusion on her observation (switch turned on, the globe turned off). Specifically, she was able to discuss the influence of her prior understandings of the current taking the easiest route through the switch, that led her to conclude that there was no current flowing through the globe. She now realises the limitation of her conclusion. Using the student outcome statements descriptors, Sheila was demonstrating achievement at level seven of the 'evaluating findings' substrand in the 'working scientifically' strand.

To track and identify Sheila's progress a second POE similar to the first was administered a week later to the class. Sheila's responses to this POE is described as follows:

An electric light globe(18W6V) functioning normally is connected to a dry cell (1.5V) and a switch as shown figure 4

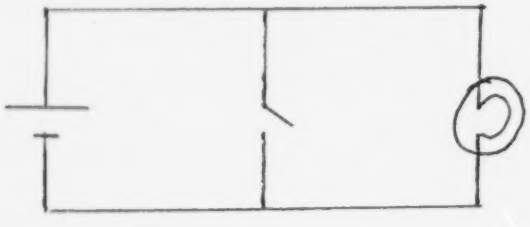

Figure 4.

1. Predict what will happen to the globe if the switch is turned on. State and explain the reason(s) for your prediction.

> The globe will turn off. This will happen because in the beginning the light will be on therefore current is flowing through. When the switch is turned on the globe will turn off because the current will divide at the junction at(and) the new amount of current flowing through the globes will not be enough to light it up.

2. When the switch is turned on what happened to the globe? State and explain the reason(s) for your observation.

> When the switch was not on the light was lit up and the reading (ammeter) was 1.5Amps. When the switch was turned on the globe turned off and the reading went down to 0.6amps. I think that the other 0.9Amps went to the wire with the switch and the light did not turn on because 0.6 is not a sufficient amount of Amps to light up the globe.

3. Compare your observation with your prediction. Are they in agreement or disagreement? Explain with your reason(s).

> My prediction and observation are in agreement with one another. In my prediction I said that the amps would divide and go to the two wires when the switch was turned on. This I believe is what happened.

4. Discuss your answers to the above three questions in your group and write down your final reasons and explanations.

> The group I was in was on the average in agreement with what I had, and we all realized that the globe went out when the switch was turned on because the current took the easist route away from the resistance.

Sheila has now demonstrated her ability to apply two characteristics of parallel circuits to make her prediction and interpret her observation of the phenomenon, namely, the total current in the circuit divides among the parallel branches, and total current in the circuit equals the sum of the current in the parallel branches. This is indicated in her prediction response statement 'the current will divide at the junction at (and) the new amount of current flowing through the globe's wire.' Also she was able to account for her observed drop in the ammeter from 1.5A to 0.6A, by a mentally computed amount of 0.9A current that went through the switch branch. Epistemologically speaking, her conception is intelligible , plausible and fruitful. She was able to describe the two characteristics of parallel circuits in her own words like 'divide at the junction' and she believes how the world actually is. That is 'the amps could divide. This I believe is what happened.' Sheila was also able to use her conception to explain why the globe did not glow. This is indicated by her observation statement 'the reading went down to 0.6 amps... is not sufficient amount of amps to light up the globe.' Ontologically speaking, her understanding of a characteristics of parallel circuits is that the total current 'divide at the junction' and is equal to the sum of the current in its parallel branches (the observed 0.6A through the globe and the calculated 0.9A through the switch.) Using Duit's (1995) ontological descriptors, Sheila has the concept of the total circuit current being divided due to a feature of the parallel circuit, namely the parallel branches, at their junction. Specifically, the resistance of each parallel branch is the ontological feature that Sheila uses to explain her observed current reduction through the globe. This is indicated by the following interview transcript excerpt:

Teacher: Looking at the diagram that you have just drawn, why does the 0.9A (current) went to the wire with the switch ?

Sheila: Um... Because that doesn't have as much a resistance because it doesn't have a light globe, the electrons take the easiest route and so more go that way (pointing at the switch).

Teacher: Which way did more current went ?

Sheila: Um... went through where the switch is .

Sheila views that the lesser resistance branch receives more current. Using Chi et al's (1996) descriptors, Sheila's view of current is a matter category, that has quantity. This is indicated by the matter based predicate 'electrons take the easiest route and so more go that way (point at the switch).' Further indication of her matter-based category is observed in her prediction predicate 'new amount of current... will not be enough to light up.' And in her observation predicate '0.6 is not a sufficient amount of Amps to light up the globe.'
The data suggest that POEs are effective in eliciting useful information on students' conceptual understanding epistemologically and ontologically. Furthermore POEs are also effective in facilitating the teacher's observations of students' achievement and profiling of progress overtime. In her first POE, Sheila was able to recount sequences of connected events like 'when the switch is turned on the light globe turned off' which corresponds to

a level one achievement of the 'transferring energy' substrand in the 'energy and change strand of the student outcome statements. Sheila also demonstrated her ability to compare her conception and conclusion for her prediction with the results and conclusion of her observation. This is indicated by her question three statement like 'My prediction and observation are in agreement...' Furthermore, she was able to compare her results and conclusion with those of other students. This is indicated by her question four statement like '... we all realised that the globe went out... because the current took the easiest route away from the resistance.' Using student outcome descriptors, Sheila's achievement corresponds to a level six of the 'evaluating findings' substrand in the 'working scientifically' strand. On another strand (energy and change) Sheila showed her ability to predict the light intensity of the globe in her second POE using the relative resistance of the parallel branches as a condition for current division. She also uses her conception to relate observed changes in the ammeter readings to changes in the amount of current received in each parallel branch. Her achievement corresponds to level four and six of the 'transforming energy' substrand. The data suggest that POEs allow the student to demonstrate changes in her achievement within and across strands and substrands over time and provide opportunity for her to document the way she develops her ideas.

Reflection

Student ideas obtained from the initial and second phase of the action research on expansion of water and solubility revealed the effect of students' prior knowledge on their prediction, observation and interpretation of the phenomenon. Furthermore, variation in students' observations suggest that uniform observation outcome may not be always assumed even for a POE designed with the intention to provide an obvious and clear observation outcome. However, as indicated by the data, one could expect a reduction in variation in students' observation outcomes.

Students' ideas obtained from the third phase of the action research on light globes revealed the common existence of ideas and beliefs held by students before formal science instruction, which are often contrary to scientists' science. The grade-9 and grade-11 students have not been taught the relationship between the operating power of light globes and resistance of their filaments for the same amount of current in a series circuit. Their prediction reason of 'brighter glow is due to more watt' and the observation reason of 'brighter glow is due to the globe being closer to the power supply' are examples of ideas held before classroom instruction. These pre-instructional ideas are also held by the grade-12 students who have been taught electrical power output of metal conductors as it relates to resistance, current and potential difference. These students who have been successful on standard forms of science achievement tests since lower school years (being the top students) have failed to use learned science (except for two of them) to interpret and analyse the phenomenon observed in the demonstration. Furthermore, the data also suggest the effectiveness of POE tasks in capturing a range of possible students' observation and prediction outcomes when worded in an open-ended format. Diagnosis of students' understanding revealed common ideas amongst students that are contrary to scientists' science across year levels. The results imply that POE tasks can be used by teachers to insightfully design learning activities and strategies that start with students' viewpoint rather than the teacher's or scientist's.

In the fourth phase of the research, the focus of data collection was on an individual student. The data suggest that POEs are effective in diagnosing the student's ability to apply her own ontological and epistemological understanding to explain specific events and phenomenon, namely the relative brightness of globes, their simultaneous lighting up and similar reading on each ammeter. Furthermore, the data suggest that POEs are effective in identifying the student's achievement across levels within a substrand of the Australian

student outcome statement and enable the teacher/researcher to observe and document a spread of achievement over a range of levels rather than a single outcome.

The fifth phase of the research also focuses on an individual student to trace her progress over time. The data obtained, suggest that POEs are effective in eliciting useful information on students' conceptual understanding epistemologically and ontologically that are incongruous and congruous to that of scientists'. The information obtained enable the teacher to use it as a basis to design a subsequent POE to track the student's progress over time. The initial information and subsequent data obtained suggest that POEs are effective in facilitating the teacher's observations of the student's progress over time. Furthermore, the data indicate that POEs provide the opportunity for the student to demonstrate changes in her achievement within and across strands and substrands over time, and also provide opportunity for her to document the way she develops her ideas.

References

Australian Educational Council (1994). *A Statement on Science for Australian Schools*. Melbourne, Australia: Curriculum Corporation.

Aguis, J. (1993). Sound and musical instruments. Investigating, 9, (4), 21-22.

Bliss, J. (1995). Piaget and after: the case of learning science. *Studies in Science Education*, 25, 139-172.

Carr, M. (1996). Interviews about instances and interviews about events. In D.F.Treagust, R. Duit, & B.J. Fraser (Eds.), *Improving teaching and learning in science and mathematics*. New York: Teachers College Press.

Chi, M.T.H. (1992). Conceptual change within and across ontological categories: Examples from learning and discovery in science. In R. Giere (Ed.), *Cognitive Models of Science: Minnesota studies in the philosophy of science* (pp. 129-160). Minneapolis, MN: University of Minnesota Press.

Chi, M.T.H., Slotta, J. D., & de Leeuw, N. (1994). From things to process: A theory of conceptual change for learning science concepts. *Learning and Instruction*, 4, 27-43.

Chinn, C.A. & Brewer, W.F. (1993). The role of anomalous data in knowledge acquisition: A theoretical framework and implications for science education. *Review of Education Research*, 63(1), 1-49.

Costa, M. (1994). Air activities for grade 6. *Investigating*, 10,(2), 17-19.

DeJong, E., Armitage, F., Brown, M., Butler, P., and Hayes, J. (1990). *Physics one*. Heinemann Educational Australia. Page 323.

Denzin, N.K. (1988). Triangulation. In J.P. Keeves (Ed.), *Educational research, methodology and measurement: An international handbook* (pp. 511-513). Sydney: Pergamon Press.

Driver, R. (1988). Theory into practice II : A constructivist approach to curriculum development . In P. Fenshem (Ed.). *Development and dilemmas in science education*. London : The Falmer Press.

Driver, R., Squires, A., Rushworth, P. & Wood-Robinson, V. (1994). *Making sense of secondary science: Research into children's ideas*. London: Routledge.

Duit, R. (1995). *Constraints of knowledge acquisition and conceptual change: The case of physics*. Paper presented at the 6th European conference for research on learning and instruction; Nijmegen, August 26 to 31, 1995.

Duit, R., Goldberg, F. & Niedderer, H. (Eds.)(1991). *Research in physics learning: Theoretical issues and empirical studies*. Kiel: IPN.

Duit, R., Treagust, D.F., & Mansfield, H. (1996). Investigating student understanding as a prerequisite to improving teaching and learning in science and mathematics. In D.F. Treagust, R. Duit, & B.J. Fraser (Eds.), *Improving teaching and learning in science and mathematics* (pp. 17-31) New York: Teachers College Press.

Education Department of Western Australia (1994). *Science student outcome statements with pointers and work samples: Working edition.* Perth

Erickson, F. (1986). Qualitative methods in research on teaching.(pp.119-161). In M.C. Wittrock (Ed.), *Handbook of research on teaching.* (3rd edn.) New York: Macmillan.

Grant, P,. Johnson, L., & Sanders, Y. (1991*). Better Links: Teaching strategies in the Science Classroom.* Victoria, Australia: STAV Publishing.

Gunstone, R.F. (1988). Learners in science education. In P. Fensham (Ed.). *Development and dilemmas in science education.* London. The Falmer press.

Hewitt, P.G. (1992). *Conceptual Physics*. Addison-Wesley Publishing Company, Inc. U.S.A. Page 531.

Hewson, P.W. (1985). Diagnosis and remediation of an alternative conception of velocity using a microcomputer program. *American Journal of Physics*,53,684-690.

Hewson, P. W. & Hennesey, M. G.. (1992). Making status explicit: a case study of conceptual change. In R. Duit, F Goldberg, and H Niedderer, (Eds.) *Research in physics learning: Theoretical issues and empirical studies* (pp.176-187). Kiel, Germany: Institute of Science Education.

Liew, C. W. & Treagust, D.F.(1995). A predict-observe-explain teaching sequence for learning about students' understanding of heat and expansion of liquids. *The Australian Science Teacher Journal*,1,42, 68-71.

Nelkon, M. & Parker, P.(1978). *Advanced Level Physics*. Heinemann Educational Books, London. Page 710.

Nusirjan. & Fensham, P. (1987). Descriptions and frameworks of solutions and reactions in solutions. *Research in Science Education*, 17, 139-148.

Osborne, R., & Freyberg, P. (1985). *Learning in Science: The implication of children's science*, Auckland: Heinemann.

Pintrich, P. R., Marx, R.W., & Boyle, R.A. (1993). Beyond cold conceptual change: the role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Education Research*, 63, 167-200.

Posner, G.J., Strike, K.A., Hewson, P.W., & Gertzog, W.A. (1982). Accommodation of a scientific conception: towards a theory of conceptual change. *Science Education*, 66, 211-227.

Scott, P.H.(1991). conceptual pathways in learning science: A case study of the development of one student's idea relating to the structure of matter. In Duit, R., Goldberg, F. & Niedderer, H.(Eds.), *Research in physics learning: Theoretical issues and empirical studies*. Kiel, IPN, 203-224.

Treagust, D.F. (1996). Conceptual change: *A multi-dimensional interpretive framework.* Paper presented at the annual meeting of the American Educational Research Association, New York City, 8-12 April, 1996.

Tytler, R. (1993). Teaching science using toys and tricks. *Investigating*, 9, 17-19.

White, R. & Gunstone, R. (1992). *Probing understanding*. London. The Falmer Press.